Detection and Retrieval of Mineral Dust Aerosols Using AERI Data

UCLA

Richard Hansell Jr. (rhansell@atmos.ucla.edu) [1], K.N. Liou [1], S.C. Ou [1], S.C. Tsay [2], J. Ji [3] and J. Reid[4]

[1] Department of Atmospheric and Oceanic Sciences, UCLA, [2] Goddard Space Flight Center, NASA, Greenbelt, Maryland
[3] University of Maryland College Park, Maryland, [4] Naval Research Laboratory, Monterey, California

1. Introduction

- The effects of mineral dust on earth's climate system remain highly uncertain (**IPCC 2007**) due in part to a lack of data particularly in the thermal IR (TIR) and an understanding of its key properties.
- We present a ground-based detection/retrieval approach for remotely sensing dust aerosol using TIR data from the GSFC NASA SMART Atmospheric Emitted Radiance Interferometer (AERI – Fig 1.1) during the United Arab Emirates Unified Aerosol Experiment (UAE^2 2004) in the UAE (Fig 1.2)
- Consistent with measured dust parameters from the NRL Mobile Atmospheric Aerosol and Radiation Characterization Observatory (MAARCO) during the UAE^2 and from prior field studies, dust microphysical models were developed to characterize the single scattering properties of dust aerosol.
- Using the CHARTS RTM, methodologies were developed to separate dust from cloud and to retrieve the dust TIR optical depths at 10μm. Case studies are presented along with validation using a collocated AERONET sun-photometer and MPLNET MPL.

Fig. 1.1 AERI system with red arrow representing downward atmospheric emissions.

Fig. 1.2 Map of UAE. Colored circles show positions of the NRL MAARCO and GSFC NASA SMART sites respectively

2. Dust Model Parameters

Model dust parameters were based on collected aerosol *in-situ data* from the NRL Mobile Atmospheric Aerosol and Radiation Characterization Observatory (MAARCO) during UAE^2 and also from prior field studies.

Dust size parameters were inferred from an aerodynamical particle sizer (APS 3321). Daily averaged size distributions from UAE^2 are shown in Fig. 2.1(a)-2.1(c) (from *Reid J.S. et al.* [2007]) with each normalized by the common-mode volume. This study used a range of volume median diameters ranging from 0.75-5 μm with geometric standard deviations of 1.9-2.0.

Dust shape parameters were based on measured shape distributions (PRIDE 2000 – *Reid E.A. et al.* [2003]) of oblate spheroids with aspect ratios (a/b) from 1.4-2.2. A compact hexagonal plate (L=a) was also modeled characteristic of the clay kaolinite. Fig. 2.2(a)-2.2(b)

Particle compositions included quartz, kaolinite and kaolinite mixed with 10% hematite and 50% calcium carbonate. The Volz [1973] bulk dust mixture was also evaluated for comparison with the pure minerals.

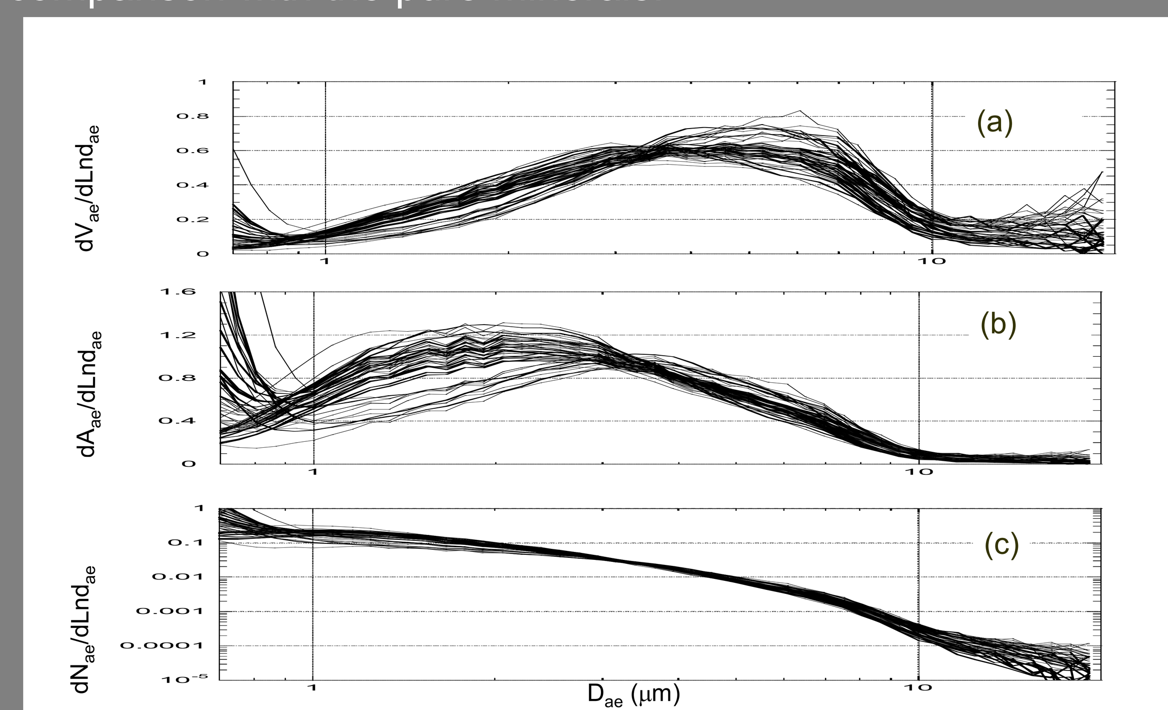

Fig. 2.1 APS size distributions (a) volume (b) surface area and (c) number

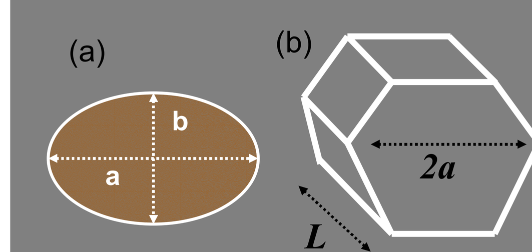

Fig. 2.2 Modeled dust shapes (a) oblate spheroid and (b) compact hexagonal plate

3. Dust Single Scattering Properties

The **T-matrix** and **Finite Difference Time Domain (FTDTD)** light scattering codes were employed to calculate the single scattering properties (SSP) for dust aerosol. The SSP were integrated in size and shape from 0.1-5.0μm in 0.2μm steps and the range of aspect ratios from 1.4-2.2 respectively using the 5 mineral compositions. Shown below are the SSP for dust particles modeled as oblate spheroids (OS) composed of quartz (Q), kaolinite/10% hematite (K/H), kaolinite/50% carbonate (K/C) and Volz. The Volz compact hexagon (CH) model is also shown for comparison.

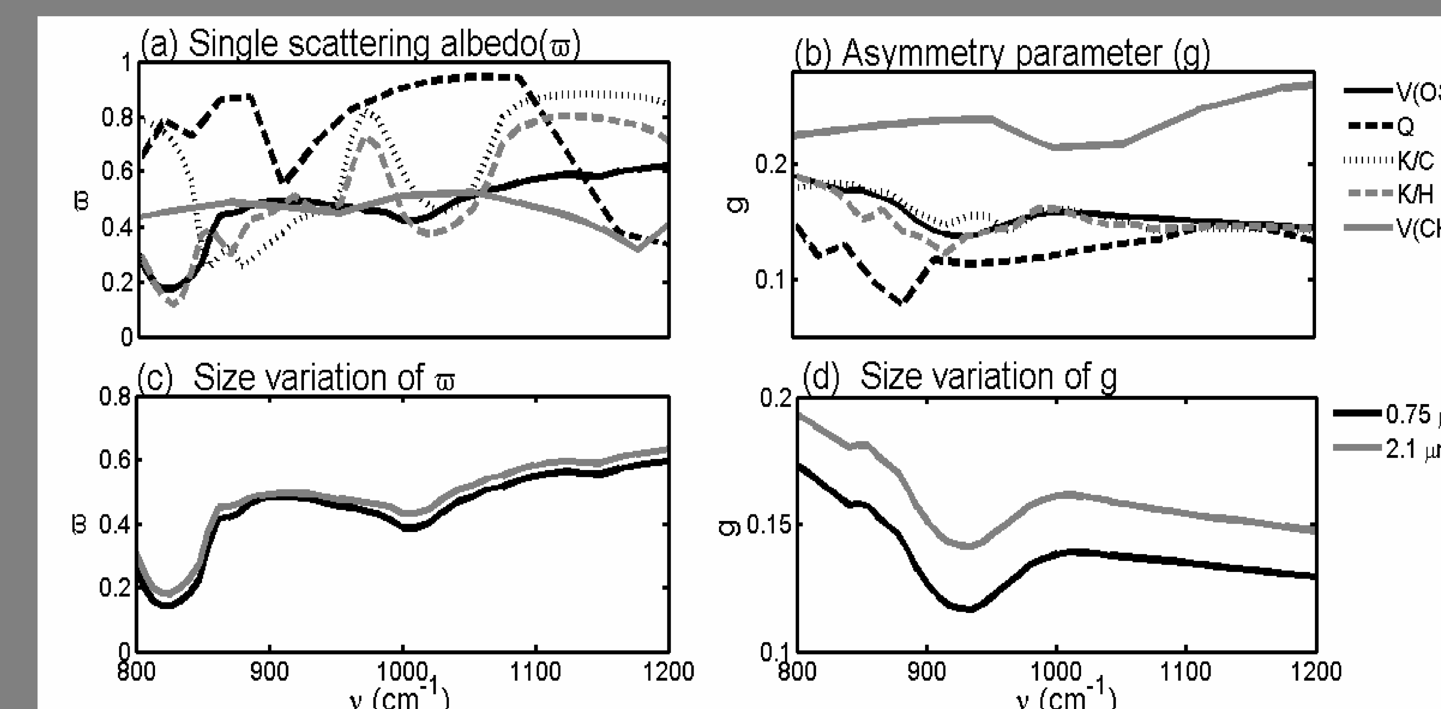

Fig. 3. Dust single scattering properties (a) single scattering albedo ϖ (b) asymmetry parameter g (c) size variation of ϖ for 0.75 and 2.1μm sized particles and (d) same as (c) but for g

Similar to *Highwood et al.* [2003], the single scattering properties are more sensitive to the refractive indices than size or shape. The spectral average and root mean square (RMS) variance of ϖ and g are 0.463±0.023 and 0.156±0.016, respectively.

4. Methodologies

- **Dust and cloud detection:** Using the developed dust models (sections 2 & 3), the CHARTS RTM (*Moncet et al.* [1997]) was employed to assess AERI brightness temperature (*BT*) sensitivity to separate dust and clouds over the TIR window within narrow 'clean' sub-bands.
- Examination of many dust/cloud scene scenarios showed dust commonly exhibits a negative *BT* difference (*BTD*) from 10-11μm whereas most clouds are positive with each depending on their respective optical depths. [Figs 4(a)-4(b)]
- **Dust retrieval:** *BT* sensitivity to dust optical depth (τ) for most minerals exhibits a strong sub-band slope dependence particularly from 1100-1200 cm^{-1}. Fig. 4(c) shows ΔBT ($BT_{dust} - BT_{clear}$) versus wavenumber at each sub-band for four optical depths using the Volz CH model. An AERI spectrum (red) is shown for comparison.
- The retrieval uses a statistical optimization approach to yield a best fit IR optical depth at 10μm

$$\chi^2 = \sum_{i=a}^{b} [\ln(\Delta BT^{i}_{calc}(\tau, a_e, T, \nu)) - \ln(\Delta BT^{i}_{aeri}(T, \nu))]^2$$

- Look-up tables (LUT) were constructed for each mineral & shape to evaluate the sensitivity of each fit with optical depths interpolated over a range from 0.05-1 in steps of 0.1. Water vapor was accounted for using two approaches: (1) AERIPLUS clear-sky profiles and (2) Precipitable water vapor (PWV) added to LUT covering the range 1.8, 2.4 and 3.0 g cm^{-2}

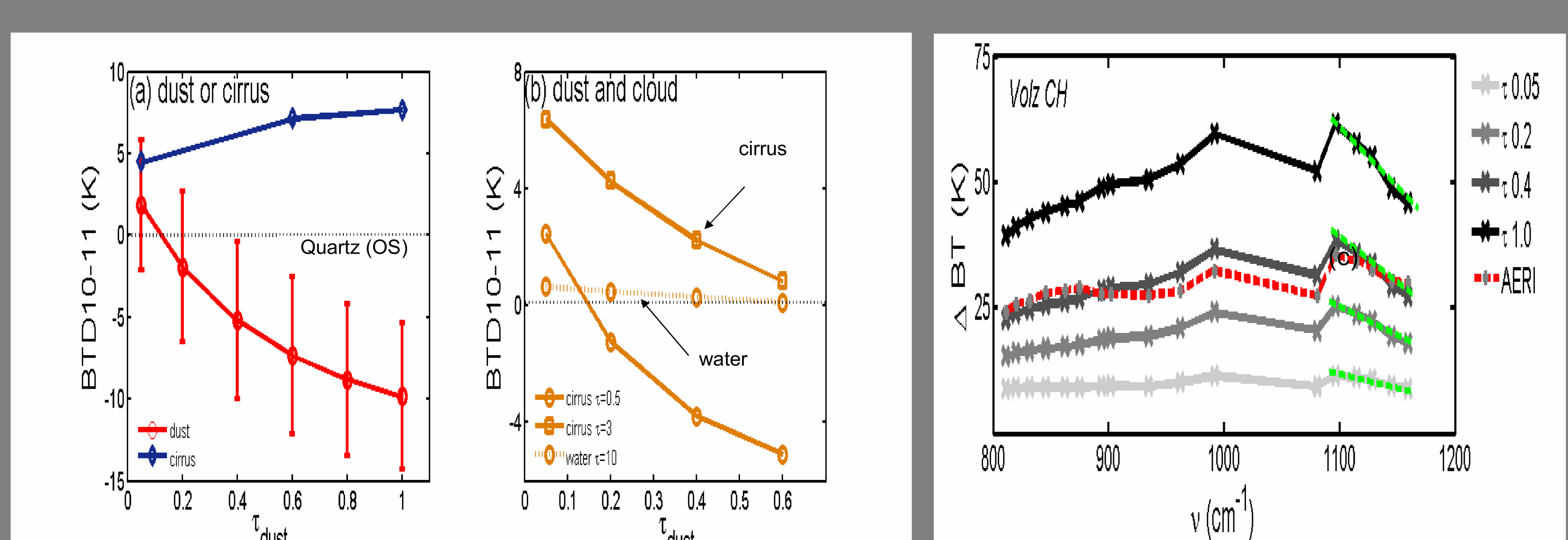

Fig 4. (a) *BTD*10-11 for dust or cirrus only. Error bars denote variability due to PWV. (b) *BTD*10-11 for dust and cloud mixed cases. (c) BT sensitivity to dust τ using Volz CH model

5. Results and Validation

- **Dust and cloud detection**: AERI separates dust from cloud employing the *BTD*10-11 technique for a cirrus case on 9/30/2004 during UAE^2. A normalized relative backscatter (NRB) plot (data from J. Campbell) from a collocated MPL at SMART (MPLNET – *Welton et al.* [2001]) given below shows heavy cirrus coverage.

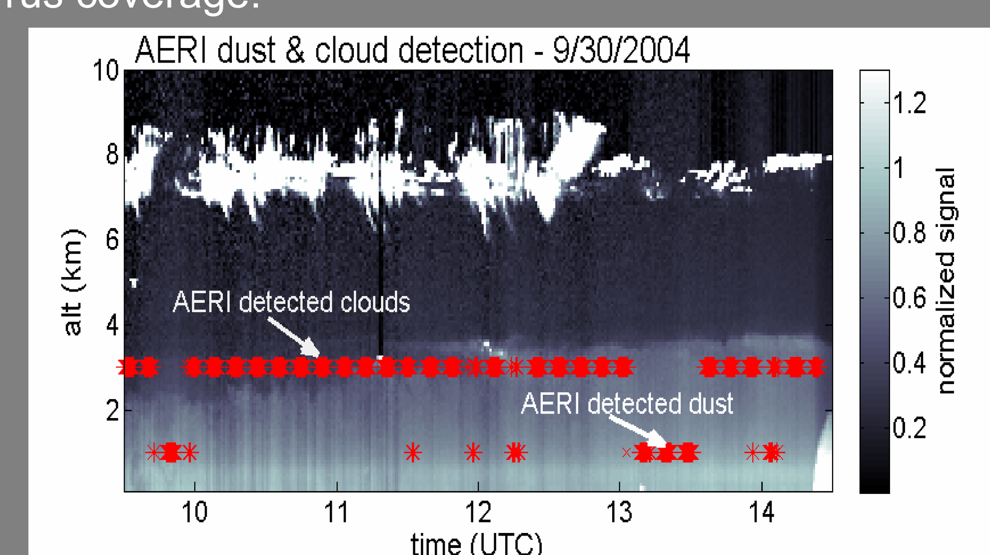

Fig. 5a. AERI dust and cloud detection for 9/30/2004 shown against the MPL detected cloud profiles. Red X markers denote AERI detected clouds and dust (clouds – top row; dust- bottom row).

- **Dust retrieval**: AERI retrieved optical depths from 9/22/2004 during UAE^2 employing PWV (Fig. 5b). The IR optical depths (10μm) are scaled to visible (0.55μm) using the corresponding ratio of extinction coefficients. Error bars denote uncertainty in particle sizing (0.75-1.75 μm). A scatter plot (Fig. 5c) shows good correlation (~78%) between AERI and AERONET

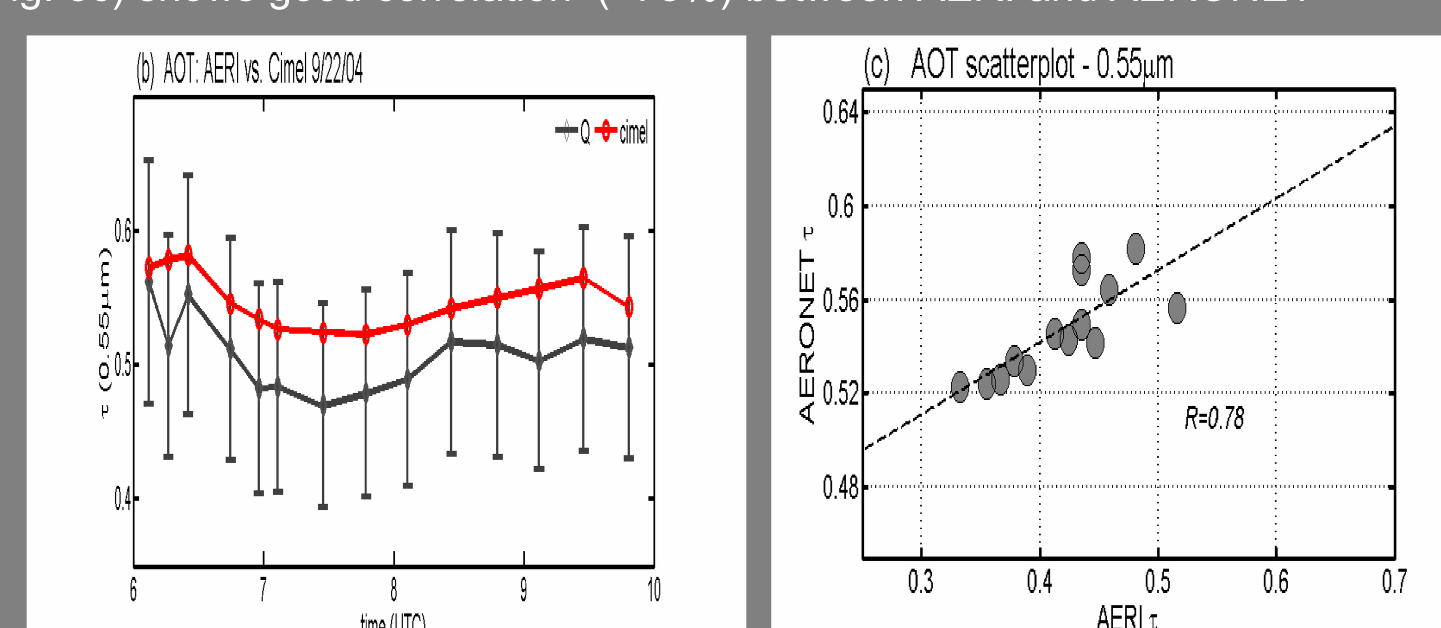

Fig. 5b. AERI retrieved dust optical depth vs. AERONET. (c) Scatter plot between AERI and AERONET retrieved optical depths.

6. Summary

- Remote sensing of dust aerosol using UAE^2 AERI TIR window data was presented.
- Dust microphysical models were constructed using *in-situ* field campaign data.
- Sensitivity studies were conducted using the CHARTS RTM to develop the AERI dust detection and retrieval methodologies.
- Case studies were presented to demonstrate the effectiveness of each approach with validation using a collocated MPL and sun-photometer.
- Validation shows that AERI can be used to effectively separate dust from clouds employing the *BTD* technique and to retrieve dust optical depths.
- The combined detection/retrieval techniques can be applied to both daytime and nighttime dust scenes and used to assess the LW dust radiative forcing.

7. References

Hansell, R.A., S.C. Ou, K.N. Liou, J.K. Roskovensky, S.C. Tsay, C. Hsu and Q. Ji (2007) Simulataneous detection/separation of mineral dust and cirrus clouds using MODIS thermal infrared window data, *Geophys. Res. Lett*. **34**, L11808, doi: 10.1029/2007G1029388

Highwood, E.J., J.M. Haywood, M.D. Silverstone, S.M. Newman, and J.P. Taylor (2003), Radiative properties and direct effect of Saharan dust measured by the C-130 aircraft during Saharan Dust Experiment (SHADE): 2. Terrestrial spectrum, *J. Geophys. Res.,* **108**, 8578, doi:10.1029/2002JD002552.

Moncet, J.L., S.A. Clough (1997), Accelerated monochromatic radiative transfer for scattering atmospheres: application of a new model to spectral radiance measurements, *J. Geophys. Res*., **102**, 21853-21866.

Reid, E.A., Reid, J.S., M. M. Meier, M.R Dunlap, S.S. Cliff, A. Broumas, K. Perry, and H. Maring (2003a), Characterization of African dust transported to Puerto Rico by individual particle and size segregated bulk analysis, *J. Geophys. Res*. **108**(D19), 8591,doi: 10.1029/2002JD002935.

Reid, J.S., E. A. Reid, S. Piketh, S. Cliff, A. Al Mandoos, A. Walker, S.C. Tsay (2007), Dynamics of Southwest Asian Dust Particle Size Characteristics with Implications for Global Dust Research *J. Geophys Res*, to be submitted.

Volz, F.E. (1973), Infrared optical constants of ammonium sulfate, Sahara dust, volcanic plumice, and flyash, *Appl. Opt*, **12**, 564-568.

Welton, E. J., J. R. Campbell, J. D. Spinhirne and V. S. Scott (2001), Global monitoring of clouds and aerosols using a network of micro-pulse lidar systems, *Proc. Int. Soc. Opt. Eng.*, **4153**, 151-158.

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